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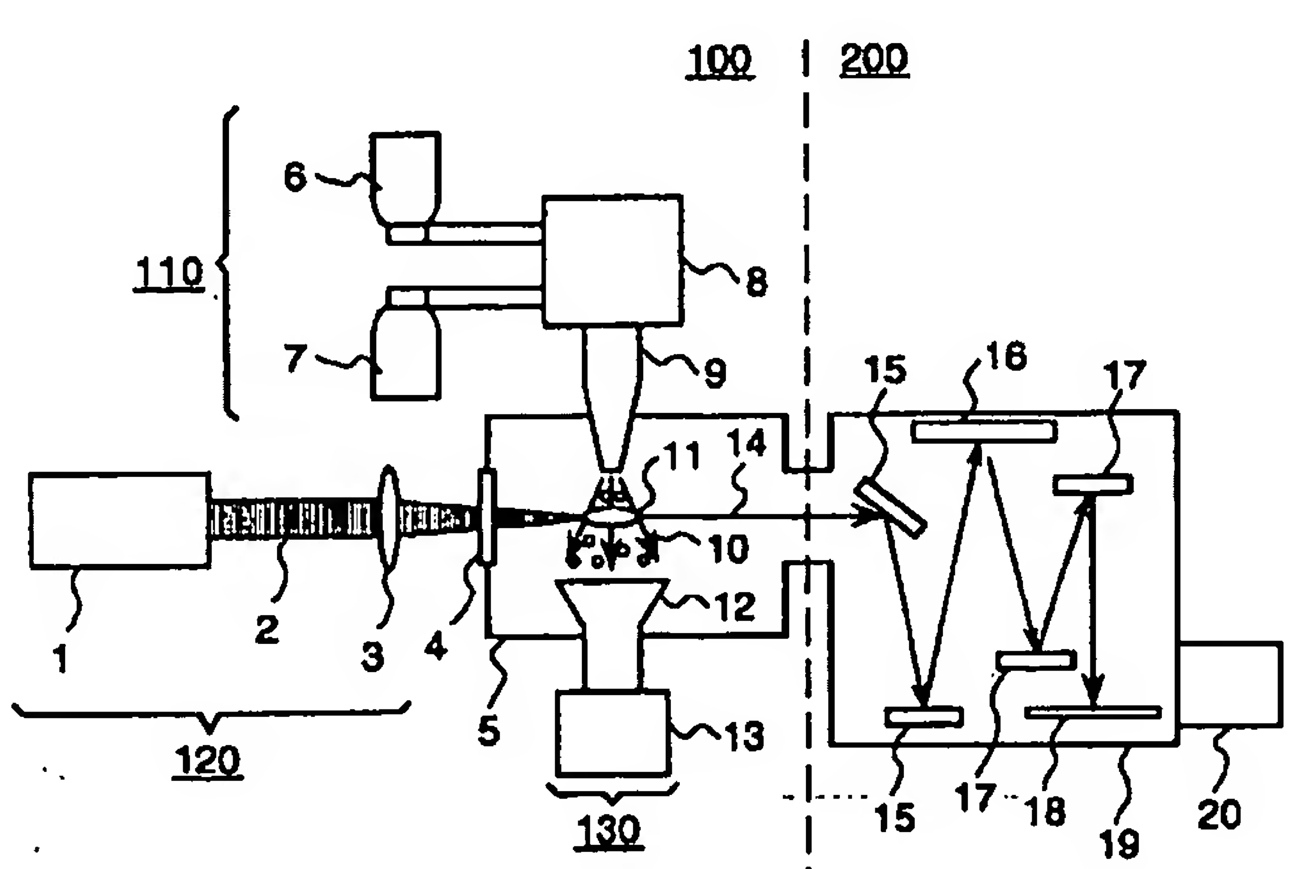
(54) **Laser plasma X-ray source, and semiconductor lithography apparatus and method using the same**

(57) A laser plasma X-ray source which has an improved X-ray conversion efficiency and minimized occurrence of debris is provided, and a semiconductor lithography apparatus using the same and a method therefor are provided. Its X-ray generation unit 100 is comprised of: vacuum chamber 5 which encases the target; target supply unit 110 which supplies a fine particle mixture gas target into vacuum chamber 5; laser irradiation unit 120 which irradiates laser beam 2 on the particle mixture gas target 10; and target recovery unit 130 which recovers unused particle mixture gas target from the vacuum chamber 5.

FIG. 1



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Description

FIELD OF THE INVENTION

This invention relates to a laser plasma X-ray source which by irradiating a laser beam on a target produces a plasma and from which to generate an X-ray.

BACKGROUND OF THE INVENTION

JP Laid-open No.6-281799 discloses that a solid target provided in the shape of a winding tape is irradiated with a laser beam so as to generate an X-ray.

JP Laid-open No.61-153935 discloses that a droplet of liquid metal is irradiated with a laser beam so as to generate an X-ray.

JP Laid-open No.2-100297 discloses that a bullet-shaped target having a diameter smaller than a spot diameter of a laser is irradiated with laser so as to produce an X-ray.

JP Laid-open No.57-41167 discloses that solidified rare gas or water particles are irradiated with a laser beam so as to produce an X-ray.

OSA, Trends in Optics and Photonics, vol.4, EXTREME ULTRAVIOLET LITHOGRAPHY, 1996, pp.66- discloses that a pressurized gas is injected into a vacuum chamber, then the injected gas is irradiated with a laser beam so as to produce an X-ray.

When a target is irradiated with a laser beam, atoms and molecules in the target are subjected to optical breakdown to ionize thereby producing a laser plasma. Then, an X-ray is generated from the laser plasma having been produced. Depending on the species of elements in the target and status thereof, an intensity of the laser beam required for the optical breakdown will change. A minimum limit value of a laser beam intensity which causes the optical breakdown is referred to as a breakdown threshold.

Optical breakdown thresholds become higher in the order of (1)gas, (2)liquid and (3)solid. In other word, a laser beam intensity required for producing a plasma using the same number of atoms can be lowered by using a solid and/or a liquid targets than by using a gas target. Therefore, in the case where liquid and solid targets are used, its X-ray conversion efficiency (expressed in energy of X-rays generated relative to energy of irradiated laser) becomes higher than in the case where a gas target is used.

However, when a solid target in a bulk or a liquid target having a diameter larger than a spot diameter of a laser beam is used, a heat generated in a region of the target irradiated by laser beam is conducted to its peripheral region thereby melting the peripheral region thereof. Then, a melt portion is caused to scatter by an expansion pressure associated with the production of the laser plasma. This scattered portion is called debris which assumes various forms such as an ionized state, cluster state and a particle with several tens μm in size. This debris attaches and damages optical elements in the vacuum chamber.

When solid and liquid targets are provided in the form of a particle having a diameter which is smaller than the spot diameter of the laser beam, the amount of debris will be reduced due to absence of particles in the periphery of the irradiated portion, with the same X-ray conversion efficiency ensured as by using the solid and liquid targets. However, it is very difficult to supply a target in the shape of particles in synchronism with irradiation of a laser beam, and thus, it is difficult to produce X-rays stably.

A target of particles prepared by freezing a chemically stable gas such as rare gases will not produce debris when melted since it turns into a chemically stable gas. However, it is difficult to supply such targets thereby preventing stable production of X-rays. Further, since frequencies of its specified X-ray are limited, and if there exists a difference from a desired wavelength, its X-ray conversion efficiency becomes substantially lowered than that of a metal target.

On the other hand, when using a gaseous target, since it has a smaller heat conduction to its peripheral portion of the target compared to the solid and liquid targets, thus not likely causing melting of the peripheral portion, a continuous supply of such gaseous target can be ensured with minimum debris thereby capable of stably producing X-rays. However, since its breakdown threshold is higher, and its atomicity density is lower, its X-ray conversion efficiency is lower than those of the solid and liquid targets.

SUMMARY OF THE INVENTION

The present invention has been contemplated to solve the above-mentioned problems associated with the prior art. The main object of the present invention is to provide a laser plasma X-ray source which can minimize formation of debris and has an improved X-ray conversion efficiency, and provide a semiconductor lithography apparatus using the same and a semiconductor lithography method therefor. The feature of the invention for accomplishing the above-mentioned object resides in that a target prepared by mixing particles in a gas is injected by a target injector into a chamber and a laser irradiation apparatus irradiates the injected target with a laser beam. According to this feature of the invention, since the heat conduction in its target prepared by mixing the particles and the gas is small, thereby preventing melting of particles in the peripheral portion of the target irradiated with a laser beam, formation of debris can be minimized.

Further, the target of a mixture of particles and the gas is injected as a fluid flow, thereby allowing a constant supply of a target flow for a laser pulse, thereby stably generating X-rays.

Still further, although a volume of the target of the

mixture of particles and gas through which a laser beam penetrates is the same as that in the case of a gas target alone, its breakdown threshold is the same as in the case of a solid target which is smaller than the case of the gas target alone. Therefore, its plasma producible region in the case of using the mixed target becomes greater than a plasma producible region using the gas target alone, and since a greater number of particles and gaseous molecules are included in these plasma producible region, the number of fine particles undergoing the optical breakdown increases than in the case of using particle target or gaseous target alone. Thereby, brightness of X-rays having been generated can be increased than in the cases where particle target or gaseous target alone is used.

Thereby, its X-ray conversion efficiency can be substantially improved.

Still further, since there exist more particles and gaseous molecules in the plasma producible region, and since a chance that optical breakdown does not take place is zero, it can be ensured that irradiation of a laser beam will always produce a laser plasma, thereby generating X-rays stably without wasting laser beams.

According to another feature of the invention, a diameter of target particles is made smaller than a diameter of the laser beam which irradiates the particles. Thereby, since more particles can exist in its plasma producible region, brightness of X-rays having been produced can be increased substantially.

According to still another feature of the invention, the gas used is a rare gas which is chemically stable. Thereby, even if it adheres to optical elements in the vacuum chamber in ionic state, it is readily neutralized by combining with electrons, as a result, minimizing formation of debris.

According to furthermore feature of the invention, the target particle comprises a low melting point metal which can be completely turned into a plasma when irradiated with a laser beam, thereby minimizing formation of debris.

According to still another aspect of the invention, the target is composed of a mixture of metal particles and a rare gas both having an identical specific X-ray wavelength. According to this feature, since the metal particles and rare gas molecules will emit X-rays having the same wavelength in a plasma, a brighter X-ray can be produced than in the case of using a target either of metal particles or rare gas alone.

According to still another aspect of the invention the features reside in that a target is provided by mixing particles with a gas, a target injector injects the target, a target recovery unit is provided opposite to the target injector to recover unused targets, and a laser irradiation unit irradiates the target present between the injector and the recovery unit with a laser beam, since particles and gaseous molecules which were not used in the production of plasma and those which returned to their steady states can be recovered, the vacuum chamber can be maintained at a low pressure, thereby preventing loss of X-rays having been produced.

According to still further aspect of the invention, the feature thereof resides in that the laser irradiation unit has a convergence lens to converge a laser beam into a linear transverse line for irradiating the targets. According to this feature, when the linearly converged laser beam is irradiated on the targets, a cigar-type plasma is produced from which a higher intensity X-ray can be obtained in the axial direction of the plasma since more X-rays are emitted in this direction.

According to furthermore aspect of the invention, the features thereof reside in that a convergence mirror is used to direct an X-ray produced by the laser plasma X-ray source of the invention to a semiconductor mask, and an X-ray reduction exposure mirror is used to reduce an X-ray reflected from the mask then to project a reduced X-ray on a semiconductor wafer. According to these features of the invention, since the laser plasma X-ray source of the invention produces less debris, damages of X-ray optical elements such as the convergence mirror, mask, X-ray reduction exposure mirror in the semiconductor lithography apparatus and of the vacuum chamber walls can be prevented. Still further, since a brighter X-ray can be supplied stably from the laser plasma X-ray source of the invention, there occurs no problem due to lack of exposure, thereby it becomes possible to shorten a period of time for exposure.

Still further, since the mixture target combining particles and gas of the invention which has a small heat conductance is prevented from forming debris upon irradiation of a laser beam even without the use of the target injector, there occurs no melt of particles in the peripheral portion of the target, thereby attaining a higher X-ray conversion efficiency than in the cases of using a target of particles alone or gaseous target alone.

According to the present invention, the following advantages can be accomplished.

Occurrence of debris can be minimized since unnecessary melting of particles is prevented by the steps of using the particle mixture gas target; injecting the mixture target into the vacuum chamber by the target injector; and irradiating the laser beam on the injected target by the laser irradiation unit. A more improved X-ray conversion efficiency can be obtained compared to the cases of using particle alone targets or gaseous target alone. Further, since targets can be supplied continuously to the laser pulses, X-rays can be generated stably. Still further, since a larger area of plasma producible region which include more numbers of particles and gaseous molecules therein compared to the cases of using gaseous target alone can be obtained, a larger number of fine particles can be optically broken down, and the brightness of X-rays having been produced can be improved substantially compared to the cases of using the particle alone target or gaseous alone target. Furthermore, a laser plasma can

be produced whenever a laser beam is irradiated without wasting the laser beam to stably produce an X-ray.

By providing particles each having a smaller diameter than that of the laser beam to irradiate thereon, a more number of particles can be included in the plasma producible region, thereby improving the brightness of X-rays having been generated.

Since rare gas is used as the gas component which is chemically stable and does not produce debris, occurrence of debris can be minimized.

Since metallic particles having a low melting point is used, the occurrence of the debris can be further reduced.

By provision of a target composed of a mixture of metallic particles and a rare gas both of which have approximately the same wavelength of specified X-rays, a more intensified brightness X-ray can be obtained.

According to the laser plasma X-ray source of the invention comprising: using a particle mixture gas target; injecting the mixture target by the target injector; recovering unused targets by the target recovery unit provided opposite to the target injector; and irradiating the targets present between the injector and the recovery unit by the laser irradiation unit, inside the vacuum chamber can be maintained at a low pressure, and loss of X-rays having been generated can be prevented.

By provision of the convergence lens which converges the laser beams from the laser irradiation unit into the linear transverse shape to irradiate the target so as to produce the cigar-shaped plasma, a more intensified X-ray can be obtained in the direction of the major axis of the cigar-shaped plasma.

By provisions of the converging mirror which directs X-ray generated by the laser plasma X-ray source of the first embodiment to the mask, and of the X-ray reduction lithographic mirror which reduces X-ray reflected from the mask and projects it on a semiconductor wafer, damages of X-ray optical components such as the converging mirror, mask and X-ray reduction lithographic mirror as well as damages of the wall of the vacuum chamber can be prevented since the occurrence of debris in the laser plasma X-ray source is minimized. Still further, since a stable and intensified brightness X-ray can be supplied from the laser plasma X-ray source, the exposure time can be reduced substantially without lack of exposure.

Still more, by irradiation of laser beam even on a mixture of particles and a gas which are not injected by the target injector, occurrence of debris can be reduced as well since its heat conductivity of the particle mixture gas target is low thereby causing no melting of particles in the peripheral region. Thus, a more improved X-ray conversion efficiency can be obtained compared to the cases of using particle alone target or gas alone target.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the invention will be more clearly understood with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic block diagram of a semiconductor lithography apparatus using a laser plasma X-ray source according to a first embodiment of the invention;

Fig. 2 shows an intensity distribution of a laser beam which is converged;

Fig. 3 shows a result of measurements of a luminous intensity distribution of visual light when a laser plasma is formed;

Fig. 4 shows frequency distributions of the numbers of breakdowns occurred in a plasma producible region;

Fig. 5 is a schematic block diagram of a laser plasma X-ray source according to a second embodiment of the invention;

Fig. 6 is a schematic block diagram of a laser plasma X-ray source according to a third embodiment of the invention; and

Fig. 7 is a schematic block diagram of a semiconductor lithography apparatus using the laser plasma X-ray source according to a fourth embodiment of the invention.

PREFERRED EMBODIMENTS OF THE INVENTION

The present inventors, by noting the advantages of a solid and liquid targets which have a high X-ray conversion efficiency and a high brightness of X-ray, and the advantage of a gas target which has a least debris, have contemplated to provide a target of fine particles of solid or liquid which has a diameter sufficiently smaller than the diameter of a laser beam. Thus, we have invented an apparatus and method for stably producing X-rays by mixing solid or liquid particle targets with a gas, and supplying its mixture by injecting into a vacuum chamber.

Further, the inventors have confirmed by experiments that a mixture target having solid or liquid particles mixed in a gas (hereinafter referred to as a particle mixture gas target) has a breakdown threshold which is the same as that of solid or fluid even if the particle mixture gas target included the gas, then it is discovered that although slightly smaller compared to a mass or tape-shaped solid or liquid targets, this particle mixture gas target has a higher X-ray conversion efficiency compared to those of a target comprising solid particles alone or liquid particles alone (hereinafter referred to as particle targets), and of a gas target alone (hereinafter referred to as a gas target).

Preferred embodiments of X-ray sources using particle mixture gas targets and semiconductor lithography apparatuses using the same according to the invention will be described in details in the following.

EMBODIMENT 1:

With reference to Fig. 1, a semiconductor lithography apparatus using a laser plasma X-ray source of a first embodiment of the invention is shown. This semiconductor lithography apparatus is comprised of an X-ray generating unit 100 which generates X-rays, and an exposure unit 200. Exposure unit 200 directs an X-ray 14 generated in X-ray generating unit 100 by convergence mirror 15 to a mask 16, then directs a mask pattern reflected from mask 16 to an X-ray reducing exposure mirror 17 which reduces the mask pattern and projects a reduced mask pattern on a surface of a wafer 18 (specimen).

X-ray generating unit 100 will be described more in detail. X-ray generating unit 100 of the invention is comprised of a vacuum chamber 5 which encloses the target flow, a target supply unit 110 which supplies a particle mixture gas as a target flow into vacuum chamber 5, a laser irradiation unit 120 which irradiates particle mixture gas target 10 with a laser beam 2, and a target recovery unit 130 which recovers unused particle mixture gas from vacuum chamber 5.

Target supply unit 110 is provided with a particle tank 6 which contains metal particles having a diameter sufficiently smaller than the diameter of a laser beam, a chemical cylinder 7 which is filled with a rare gas, a mixer 8 which mixes metallic particles supplied from particle tank 6 and a rare gas supplied from chemical cylinder 7, and a supply nozzle 9 which injects a particle mixture gas formed in mixer 8 into vacuum chamber 5.

Laser irradiation unit 120 is provided with a laser beam generator 1 which produces laser beam 2, and a condenser lens 3 which converges laser beam 2. It is preferable for laser beam generator 1 to be able to generate a YAG laser or excimer laser as laser beam 2 having a pulse width less than several tens ns and an output per pulse of several tens mJ to several tens J. Laser beam 2 is converged by condenser lens 3 into a diameter of several tens to several hundreds μm on the particle mixture gas target in vacuum chamber 5. In order advantageously to be able to produce laser plasma 11, an energy density on particle mixture gas target 10 is preferably in a range of 10^{15} to 10^{22} W/m^2.

Target recovery unit 130 is provided with a recovery duct 12 which recovers metal particles and rare gas having been supplied into vacuum chamber 5 but were not used in the plasma production or returned to its steady state, and a recovery tank 13 therefor.

Within vacuum chamber 5, there are disposed oppositely an injection port of supply nozzle 9 and a recovery opening of recovery duct 12. Laser beam 2 emitted from laser irradiation apparatus 120 passes through a laser beam transmission window 4 provided in the wall of vacuum chamber 5 and irradiates particle mixture gas target 10 having been injected from supply nozzle 9. Inside of vacuum chamber 5 is maintained at a low pressure by a vacuum pump (which is not shown). For example, assuming that a pressure inside vacuum chamber 5 is 10^{-2} to 10^{-3} torr, and a pressure inside supply nozzle 9 is several torr, then particle mixture gas target 10 is injected into the chamber in a state of fluid flow. Then, remaining particle mixture gas target 10 unused in the plasma formation or returned to its steady state are recovered from recovery duct 12 to be removed from vacuum chamber 5.

When a focused laser beam 2 irradiates particle mixture gas target 10, metal elements and rare gas molecules in the particle mixture gas target 10 undergo an optical breakdown to become ionized under intense electrical fields due to laser beam 2. Electrons generated in ionization of the metal elements and rare gas molecules further absorb energy of laser beam 2 through the process of the inverse bremsstrahlung and the like to become heated, thereby producing a high temperature and high density laser plasma 11 in a region through which laser beam 2 has penetrated.

Temperatures and densities of electrons of laser plasma 11 differ depending on species of metal particles and rare gases contained in particle mixture gas target 10, and also depending on types of lasers and their conditions used. However, it is preferable if a plasma can be produced which has an electron temperature more than several hundred eV, and an electron density of approximately 10^{20} to 10^{22}/cm^3.

An X-ray having a continuous spectrum is emitted from laser plasma 11 through the bremsstrahlung process of electrons in laser plasma 11, and by free-free transition and free-bound transition in a recombination process of the plasma. Further, a specificity X-ray is emitted through a bound-bound transition in the recombination process of the plasma. X-rays emitted from laser plasma 11 are utilized in exposure unit 200 provided adjacent thereto.

A relationship between the number of particles present in the plasma producible region and the generation of X-rays will be described in the following paragraphs.

Figure 2 shows a relationship of a distribution of laser beam intensities relative to the shape of laser beam 2 converged by convergence lens 3. The smaller the diameter of laser beam 2 becomes, the greater the laser beam intensity becomes. In the region of particle mixture gas target 10 which is penetrated by laser beam 2, a portion thereof having a laser beam intensity greater than the breakdown threshold undergoes an optical breakdown thereby producing a laser plasma, while another portion thereof having a laser beam intensity lower than the breakdown threshold will not produce a plasma. This portion where the laser plasma can be generated is referred to as a plasma producible region.

Assuming that a diameter of particles used is sufficiently smaller than the diameter of a cross-section of the laser beam having been converged, a probability that (x) number of particles exist in the plasma producible region is expressed by the following equation

according to the Poisson distribution, where a volume of the plasma producible region is V (m^3), and a particle density in particle mixture gas target 10 is n ($/m^3$),

$$K(x)=\frac{\alpha^X}{X!}e^{-\alpha} \quad \text{eq. 1}$$

where $\alpha=nV$.

Therefore, by obtaining volume V of the plasma producible region which is determined by the breakdown threshold of the particles used and substituting the same in equation 1 above, and by varying the particle density (n) of the particle mixture gas, it becomes possible at a probability of K(x) to set the number of particles present in the plasma producible region at a desired value.

Now, a relationship between the number of particles present in the plasma producible region when particle mixture gas target 10 was irradiated with laser beam 2 to produce laser plasma 11, and the number of particles which underwent optical breakdown will be described in the following. In our experiments, a second harmonic (532 nm wavelength) of YAG laser was used as laser beam 2 which has an output power of 100 mJ/pulse (10 ns pulse width), and the diameter of the laser convergence cross-section was set approximately at 10 μm. As its particle mixture gas, particles having a diameter of 0.5 μm and a rare gas were used.

Figure 3 shows a result of measurements of luminance intensity distributions of visual light obtained when a laser plasma was formed by irradiating one pulse laser beam in a direction of laser irradiation (in the direction of z in Fig. 2). When the particles (metal particles and rare gas) are ionized to form a plasma and emit a high intensity light, namely, when the particles undergo the optical breakdown, it is measured as a peak of the luminance intensity. By way of example, when there exists one such particle which was optically broken down in the plasma producible region, one peak appears as indicated in Fig. 3(a), and when there exist two such particles which were optically broken down, there appear two peaks as indicated in Fig. 3(b).

Frequency distributions of the number of the particles (experimental result) which were optically broken down when one pulse laser was irradiated to produce the laser plasma, and frequency distributions of the number of the particles which were calculated to have been optically broken down using the Poisson's distribution are compared in Fig. 4 for each average number of particles (α) in the plasma producible region.

When an average number of particles (α) is approximately at 1.5 or less, calculated values and experimental values are found to agree with one another, thereby verifying that the particles present in the plasma producible region are optically broken down in accordance with the theory. Further, in this case, a frequency of a status in which no laser plasma is generated upon laser beam irradiation (i.e., a status of zero breakdown) is observed to be high.

On the other hand, when the average number of particles (α) is 6.6, the frequency distribution of the experimental values is shifted greatly from that of the calculated values. Namely, the number of particles having been optically broken down experimentally obtained is smaller than the calculated value. This is considered because that since the particles which have been optically broken down are allowed to absorb the laser beam, when many particles are optically broken down, there occurs a shortage in the laser beam intensity, thereby preventing more particles from being optically broken down. However, by further increasing the laser beam intensity, the number of particles to be optically broken down can be increased.

In addition, in this case described above, since the chance of frequency that no optical breakdown takes place (i.e., the frequency that the number of particles which are optically broken down is zero) is none, a laser plasma is always ensured to be formed upon irradiation of the laser beam. Therefore, such conditions of this case are rather preferable for stably generating X-rays without wasting any laser beams.

According to this first embodiment of the invention, the following advantages can be achieved.

According to this embodiment of the invention in which the particle mixture gas target is used which includes metal particles having a diameter smaller than the diameter of the focused laser beam, and the rare gas, an improved X-ray conversion efficiency higher than those obtained by using metal particle target alone or rare gas target alone is achieved.

Since the particle mixture gas target of the invention has a smaller heat conduction, there hardly occurs melting of the metal particles in the peripheral portion of the laser irradiated region, and since the rare gas molecules do not turn into debris, formation of debris can be minimized.

Although the volume of the particle mixture gas target which is penetrated by a laser beam is the same as a volume of the rare gas target which is penetrated by the same laser beam, since the breakdown threshold of the particle mixture gas target which is the same as that of the solid metal target is lower than that of the gaseous target, its plasma producible region is larger than that of the gaseous target. Further, since more metal particles and rare gas molecules are contained in this plasma producible region, the number of particles subject to the optical breakdown increases than in the cases of using a metal particle target alone and a rare gas target alone, thereby substantially increasing the luminance of X-rays generated.

Still further, since more particles are contained in the plasma producible region, the frequency of chance that no optical breakdown takes place is zero. Thereby, whenever a laser beam is irradiated, a laser plasma is always ensured to be produced, thereby stably generat-

ing X-rays without wasting any laser beams.

According to this embodiment of the invention, since the particle mixture gas target provided by mixing metal fine particles and rare gas is injected into the vacuum chamber 5 in the form of a fluid flow, then, a laser beam is irradiated on the injected fluid flow of particle mixture gas target, the targets can be supplied without interruption, thereby ensuring X-rays to be generated stably.

According to still another feature of the invention, since unused targets which were not used in the generation of the plasma are recovered, inside the vacuum chamber 5 can be maintained at a low pressure thereby preventing absorption of X-rays by the gases present in vacuum chamber 5 so that loss of X-rays having been generated can be prevented.

Although the metal particles were used in this embodiment of the invention, it is not limited thereto, and any materials other than the metals which can be turned into a plasma to produce X-rays can be used. Further, if low melting point particles are used, since they can be fully atomized in the plasma producible region, formation of debris can be suppressed.

Further, it is preferable for the solid or liquid particles and for the gas for use in the particle mixture gas target to select species of elements which generate the same specificity X-ray which has the same wavelength as that of a desired X-ray. In the laser plasma, since materials can be ionized up to an extremely high valence, specificity X-rays not only of K or L shells but also of M shell or more can be generated. For example, if fine particles of elements such as Sn or Sb are used, since Sn or Sb has a specificity X-ray in the vicinity of 13 nm as for its M shell, an X-ray in proximity to 13 nm in the soft X-ray region can be obtained. Further, if Xe is used as the gas which emits a specificity X-ray in proximity to 13 nm, an X-ray in proximity to 13 nm can be obtained. If a target which is prepared by mixing fine particles of element such as Sn or Sb with Xe gas is used, an X-ray in the vicinity of 13 nm which has a brighter luminance compared to the other targets which include only either one of the above two can be obtained.

EMBODIMENT 2:

A second embodiment of the invention will be described with reference to Fig. 5. The features of this second embodiment reside in that it has added a directivity of emission to the X-rays produced in the first embodiment, and that a debris recovery unit is provided for recovering debris which are scattered in the direction of emission of X-rays.

In the same manner as in the first embodiment, a fine particle mixture gas injected into a vacuum chamber (not shown) from supply nozzle 9 is irradiated with laser beam 2 which is converged traversal to the flow of the mixture gas by a convergence lens 3 to generate an X-ray. In this second embodiment of the invention, convergence lens 3 which converges laser beam 2 into a linear shape is used. An electron gun (not shown) is provided outside the vacuum chamber for irradiating electron beam 22 on X-rays having been emitted through a window (not shown) of the vacuum chamber, and an ion recovery electrode 24 which is applied with a negative voltage is provided in the circumference of X-rays generated.

When laser beam 2 which was converged into the linear shape transversely to its flow is irradiated on fine particle mixture gas target 10, a cigar-shaped laser plasma 11 is generated and more X-rays 14 is emitted in the direction of a major axis of laser plasma 11. By providing directivity of emission to X-rays, a more intense X-ray can be obtained.

When irradiated with electron beam 22, debris 21 in the form of particles or atoms having been scattered in the direction of the major axis are positively-ionized. Positively ionized debris 21 are then attracted by ion recovery electrode 24 to be completely recovered. This recovery electrode 24 also can recover other scattered debris having been ionized in the process of plasma production. Thereby, debris 21 from an outlet (not shown) of X-rays can be substantially reduced, thereby preventing damages of X-ray optical elements and the wall of the vacuum chamber.

Also, it can be arranged such that instead of the recovery electrode 24 which recovers ionized debris 21 by electrical field, the orbit of the ionized debris can be changed by magnetic field so that debris 21 can be prevented to advance into the outlet of X-rays.

EMBODIMENT 3:

A third embodiment of the invention will be described with reference to Fig. 6. This is an example of a laser beam plasma X-ray source using a fine particle mixture gas according to the invention in which laser beam 2 is irradiated by two different pulses having a difference in time of emission.

As a means for producing and irradiating two pulses different in time sequence, a laser beam splitter delay optical system 26 is used. This laser beam splitter delay optical system 26 includes a beam splitter 27 which splits a laser beam from laser generator 1 into two parts, a mirror 28 which functions to lengthen an optical path of a splitted laser beam than that of non-splitted laser beam, and a beam mixer 29 which synthesizes two laser beams into one laser beam 2. Pulses of these two laser beams are caused to delay in times of irradiation from each other in proportion to a difference between their optical paths.

A first pulse irradiated on fine particle mixture gas target 10 produces laser plasma 11. Then, a second pulse is used to heat laser plasma 11, thereby improving the efficiency of X-ray generation. Further, since fine particles having been unable fully to fission into atomic

states by the first pulse are heated further by the second pulse so as to completely fission, occurrence of particle debris in the plasma producible region can be minimized.

Further, in order to accomplish the advantage of the third embodiment of the invention, it is not limited to the use of laser beam splitter delay optical system 26, but two laser generators 1 can be used as well to the same effect.

According to the third embodiment of the invention, there are such advantages that an higher X-ray generation efficiency can be obtained, and that occurrence of particle debris can be suppressed.

EMBODIMENT 4:

A fourth embodiment of the invention will be described with reference to Fig. 7. According to this fourth embodiment of the invention, a separator 30 for separating between metal fine particles and rare gas is provided to the target recovery unit 113 of the first embodiment of the invention for returning separated fine particles and rare gas to the original particle tank 6 and gas cylinder 7 for recycling.

Thereby, according to this fourth embodiment of the invention, there are such advantages that maintenance of the equipment can be reduced substantially, and that a running cost using a costly rare gas such as Xe gas can be reduced substantially.

Claims

1. A laser plasma X-ray source for generating an X-ray from a plasma which is produced by irradiating a laser beam on a target, comprising:

   a mixture of particles and a gas as said target;
   a target injector for injecting said target into a vacuum chamber; and
   a laser beam irradiation unit for irradiating said laser beam on said target having been injected.

2. A laser beam X-ray source according to claim 1, wherein said particles have a diameter which is smaller than a diameter of the laser beam irradiated on said target.

3. A laser beam X-ray source according to claim 1, wherein said gas is a rare gas.

4. A laser beam X-ray source according to claim 1, wherein said particles are made of a metal having a low melting point.

5. A laser beam X-ray source according to claim 1, wherein said target comprises a mixture of metallic particles and a rare gas both of which have substantially a same wavelength in their specificity X-rays.

6. A laser plasma X-ray source for generating an X-ray from a plasma which is produced by irradiating a laser beam on a target, comprising:

   a mixture of particles and a gas as said target;
   a target injector for injecting said target into a vacuum chamber;
   a recovery port provided opposite to said target injector for recovering said target; and
   a laser irradiation unit for irradiating said target with said laser beam; wherein
   said laser irradiation unit irradiates said laser beam on said target between said injector and said recovery unit.

7. A laser plasma X-ray source according to claim 1, wherein said laser irradiation unit comprises a converging lens which converges said laser beam into a linear line which is transverse to a flow of said target.

8. A semiconductor lithography apparatus comprising:

   a laser plasma X-ray source according to claim 1;
   a converging mirror which directs an X-ray generated in said laser plasma X-ray source to a mask; and
   an X-ray reduction exposure mirror which reduces X-rays reflected from said mask and projects the reduced X-rays on a semiconductor wafer.

9. A semiconductor lithography method for producing a plasma by irradiating a laser beam on a target, generating an X-ray from said plasma, and directing said X-ray having been generated to a semiconductor wafer to expose a semiconductor device pattern on said semiconductor wafer, comprising the steps of:

   mixing particles and a gas;
   injecting a mixture of said particles and said gas into a vacuum chamber; and
   irradiating a laser beam on a target of said mixture of the particles and the gas.

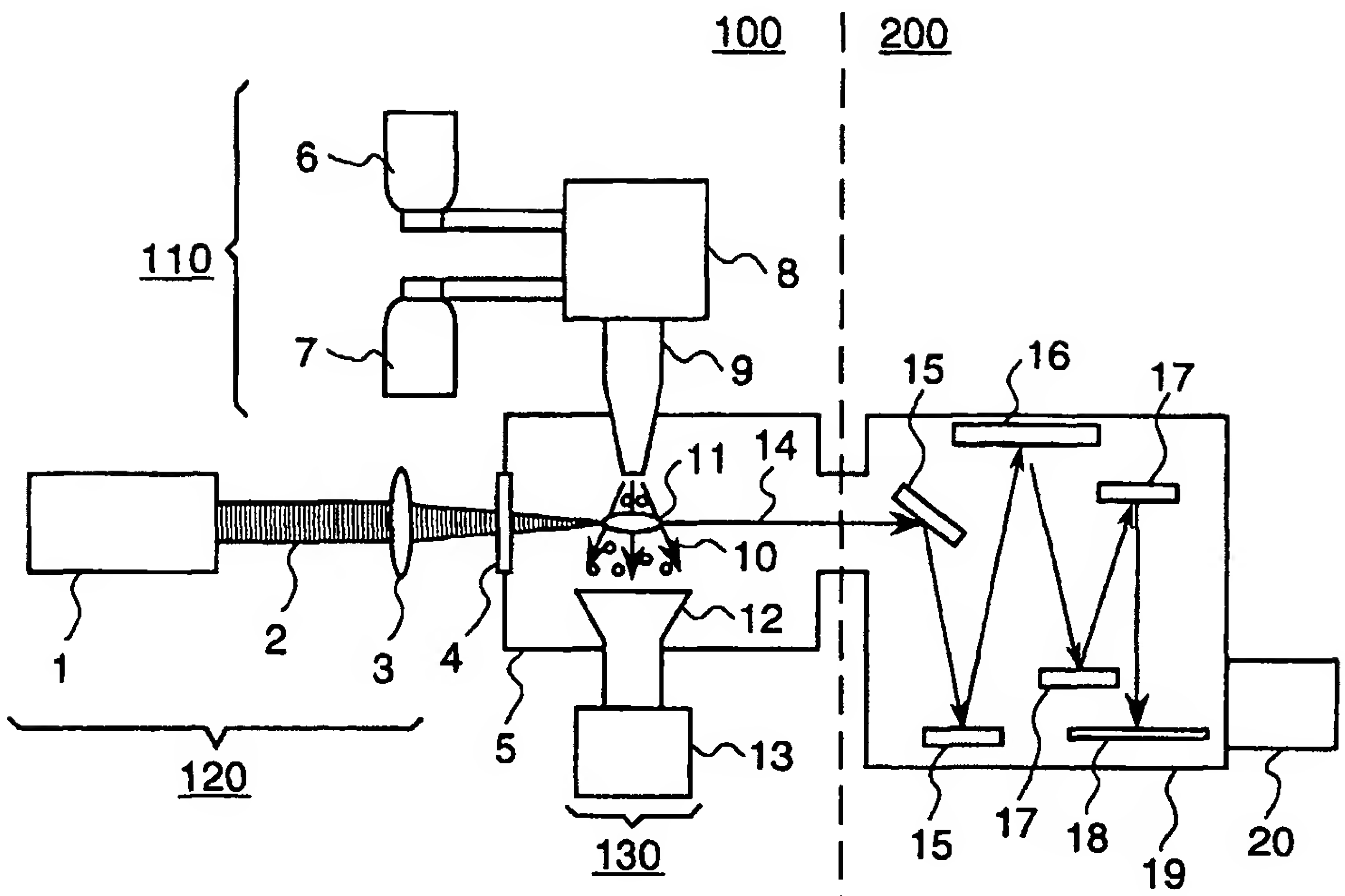
10. A laser plasma X-ray source for generating an X-ray from a plasma which is produced by irradiating a laser beam on a target, wherein said target comprises a mixture of particles and a gas.

11. A semiconductor lithography method for producing a plasma by irradiating a laser beam on a target, generating an X-ray from said plasma, and directing said X-ray having been generated to a semiconduc-

tor wafer so as to expose a semiconductor device pattern on said semiconductor wafer, comprising the steps of:

mixing particles and a gas; and
irradiating the laser beam on a target of the mixture of said particles and said gas.

FIG.1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200
110
6
7
8
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10
11
12
13
14
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16
17
18
19
20
120
130

FIG.2

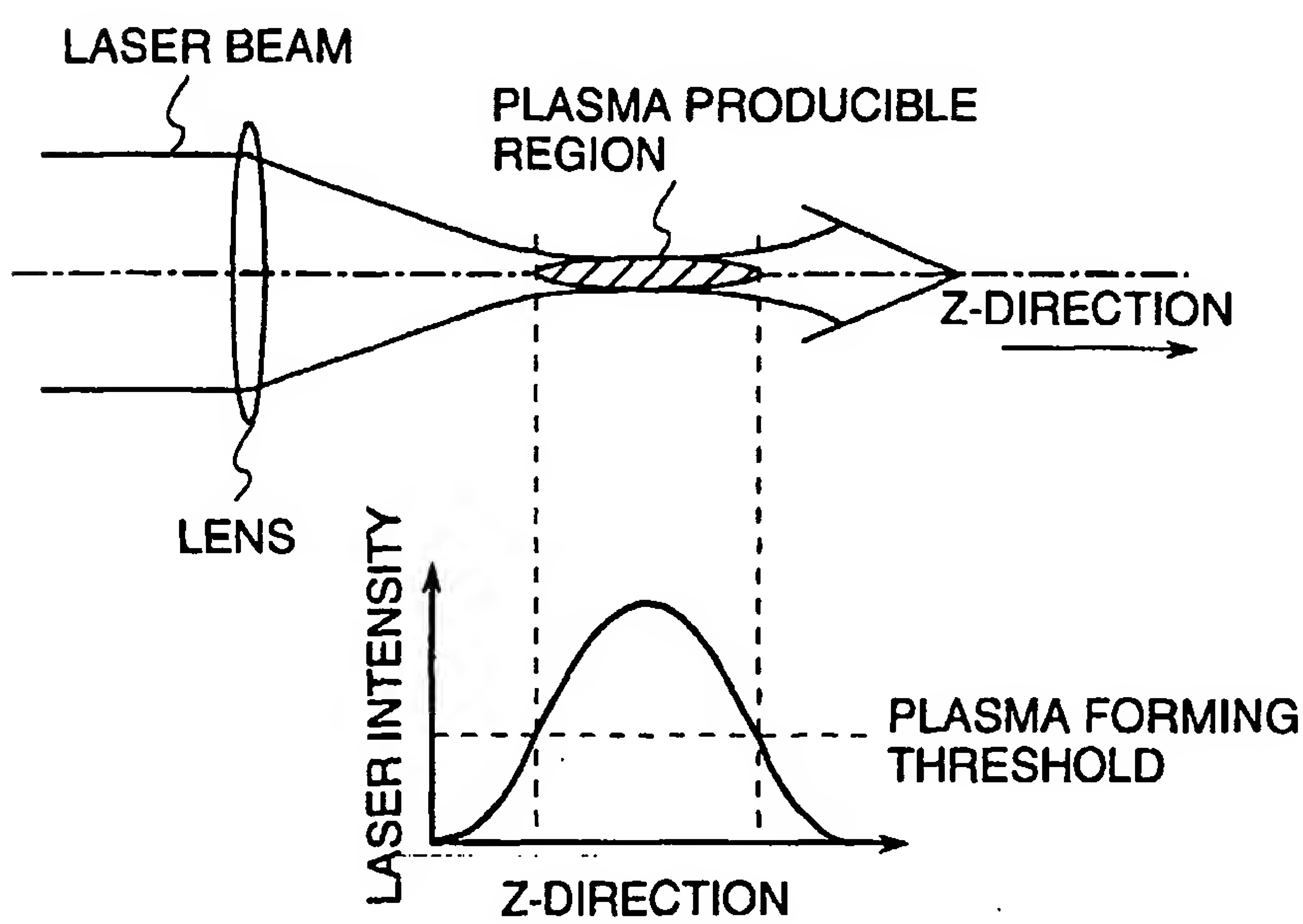
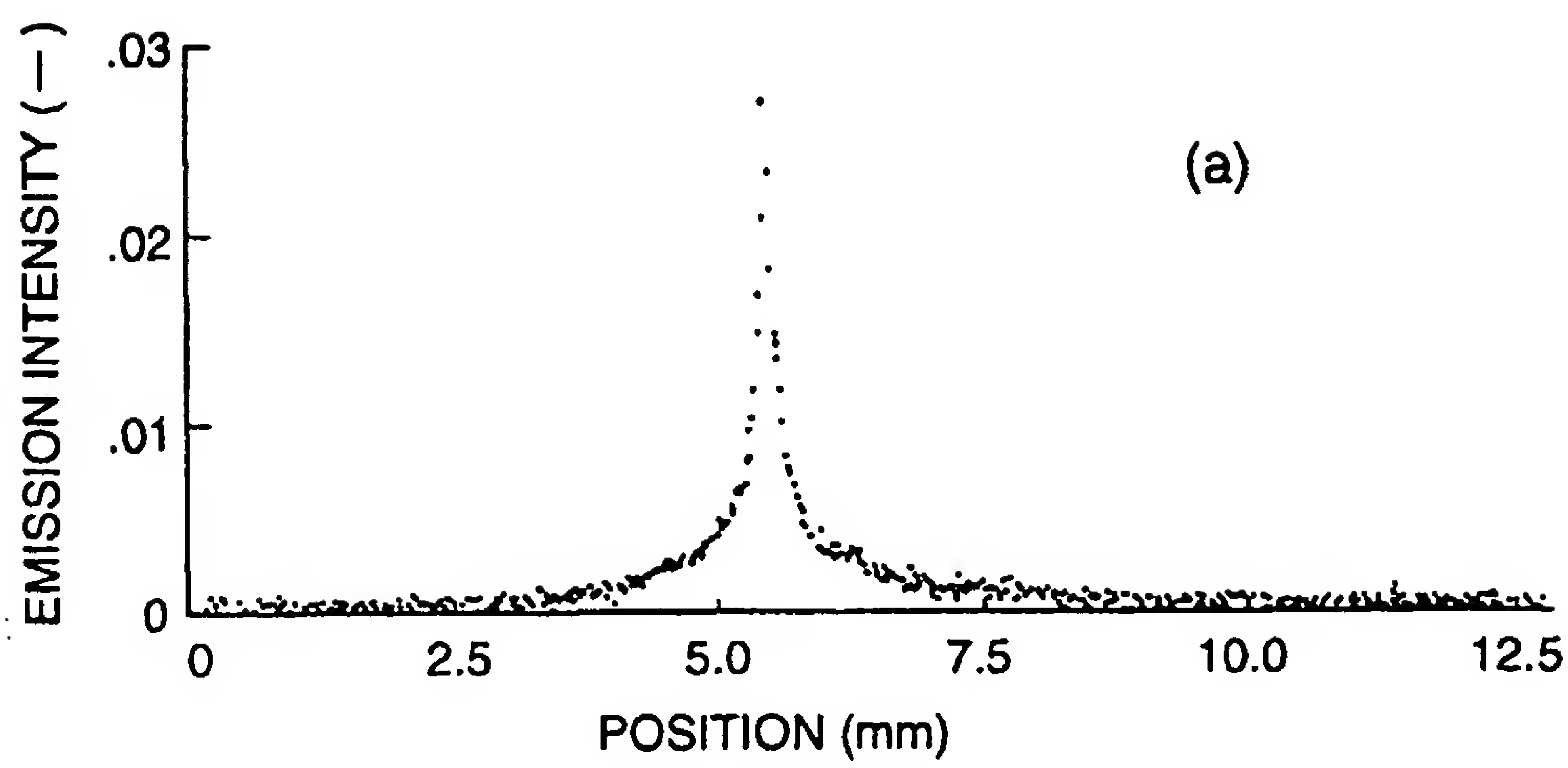

LASER BEAM
PLASMA PRODUCIBLE
REGION
Z-DIRECTION
LENS
LASER INTENSITY
PLASMA FORMING
THRESHOLD
Z-DIRECTION

FIG.3


(a)
EMISSION INTENSITY (—)
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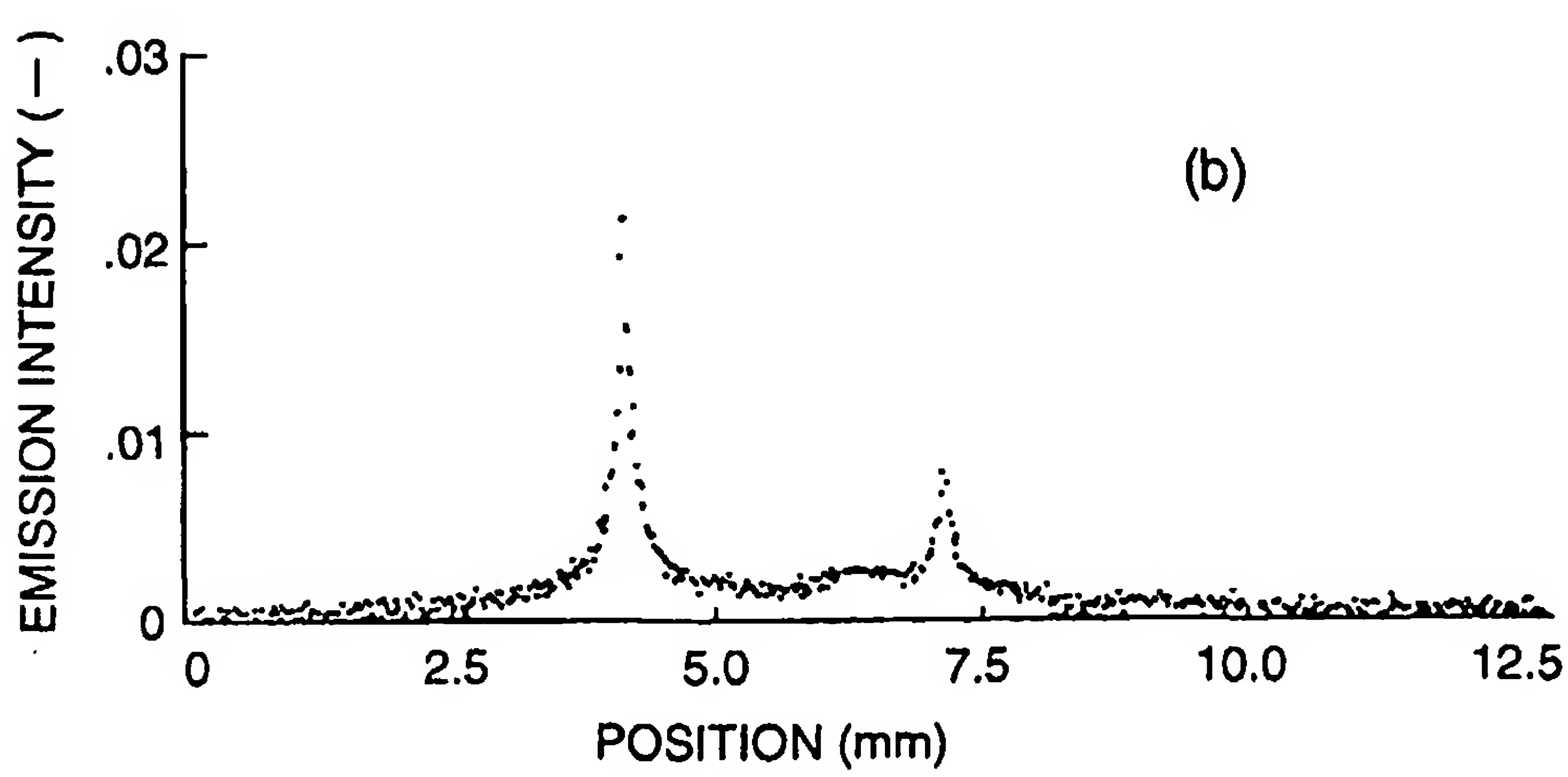
.02
.01
0
0
2.5
5.0
7.5
10.0
12.5
POSITION (mm)


(b)
EMISSION INTENSITY (—)
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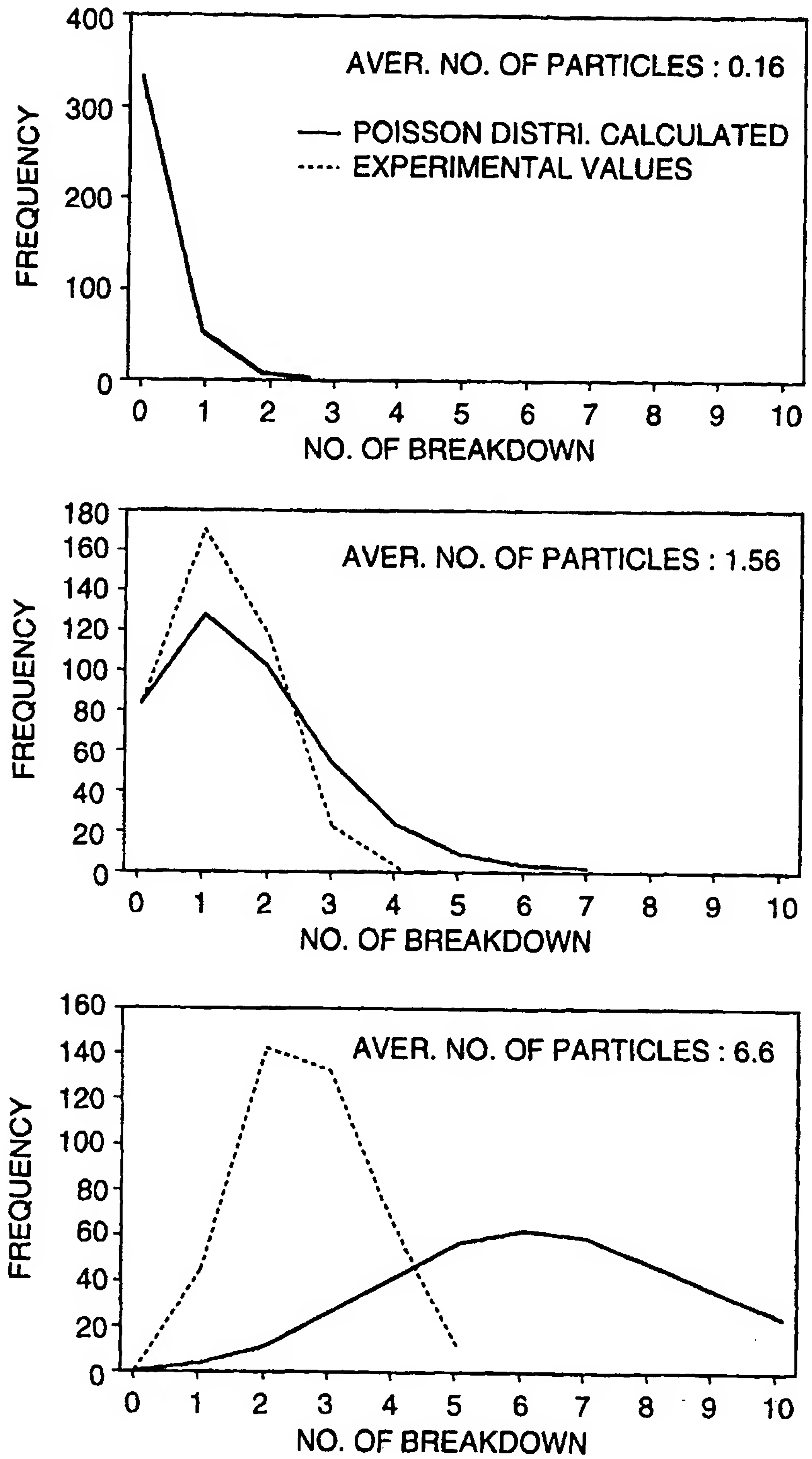
.02
.01
0
0
2.5
5.0
7.5
10.0
12.5
POSITION (mm)

FIG.4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200
100
0
FREQUENCY
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POISSON DISTRI. CALCULATED
EXPERIMENTAL VALUES
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NO. OF BREAKDOWN
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160
140
120
100
80
60
40
20
0
FREQUENCY
AVER. NO. OF PARTICLES : 1.56
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120
100
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FREQUENCY
AVER. NO. OF PARTICLES : 6.6
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NO. OF BREAKDOWN

FIG.5

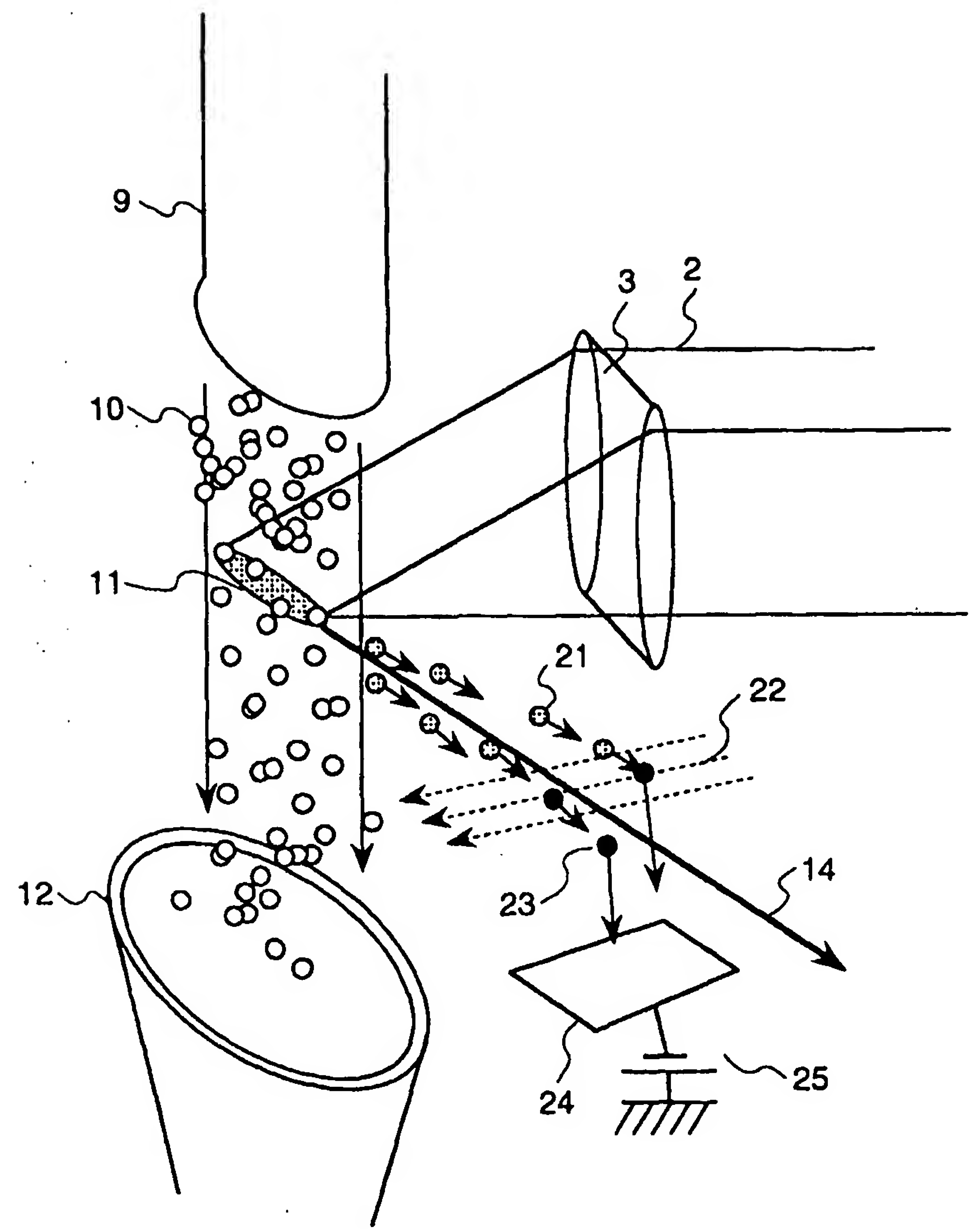

FIG.6

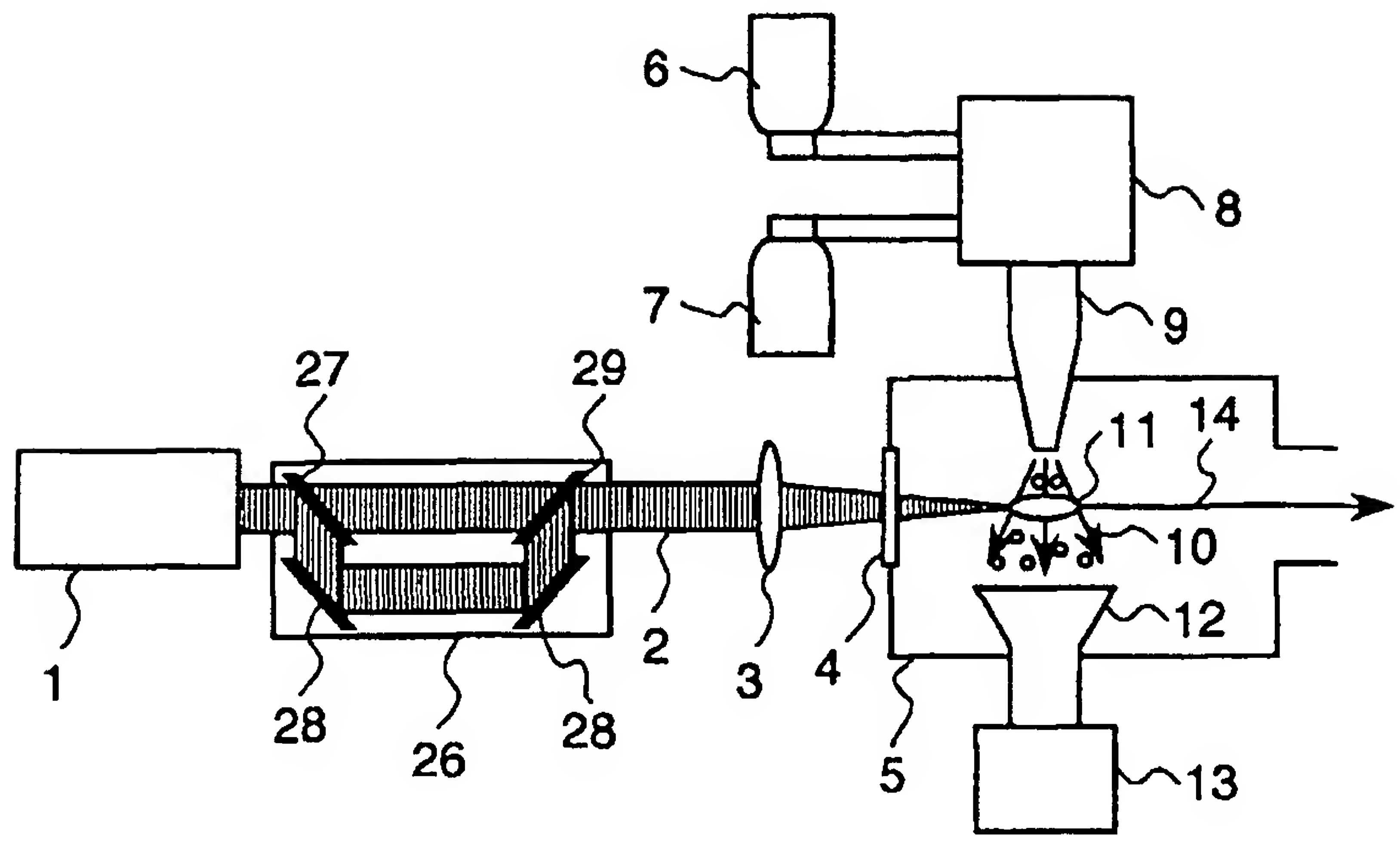
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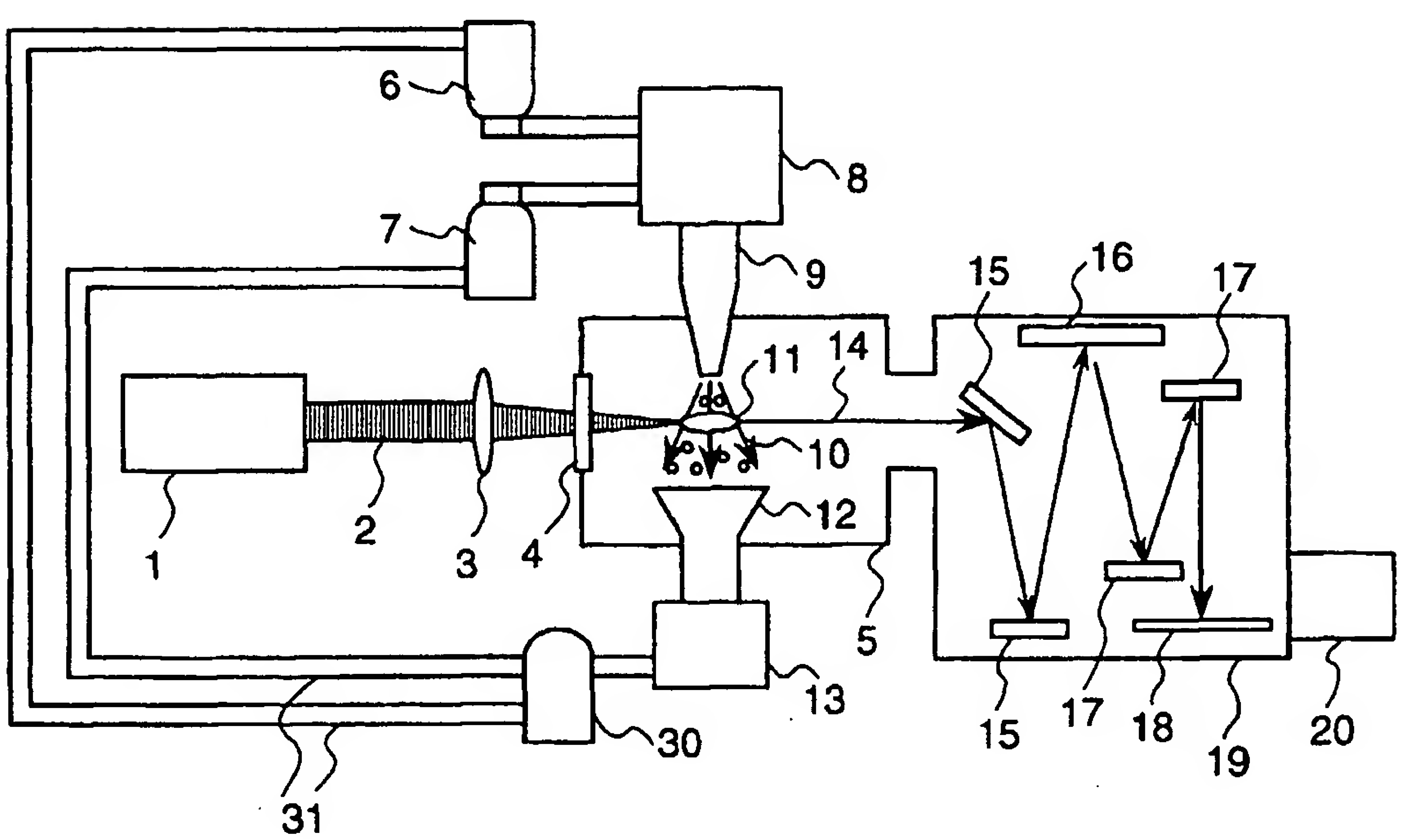
FIG.7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31
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19
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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 1013

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 577 092 A (G.D. KUBLAK ET AL.) 19 November 1996 * column 1, line 26 - column 3, line 47 * * column 4, line 42 - column 6, line 15 *	1,3,10	H05G2/00 G03F7/20
Y		2,7,9,11	
A	---	6	
Y	P. CELLIERS ET AL.: "OPTIMIZATION OF X-RAY SOURCES FOR PROXIMITY LITHOGRAPHY PRODUCED BY A HIGH AVERAGE POWER ND:GLASS LASER" JOURNAL OF APPLIED PHYSICS., vol. 79, no. 11, 1 June 1996, NEW YORK US, pages 8258-8268, XP002063259 * the whole document *	9,11	
A	---	1,3,6,8	
Y	H. FIEDOROWICZ ET AL.: "X-RAY EMISSION FROM LASER-IRRADIATED GAS PUFF TARGETS" APPLIED PHYSICS LETTERS., vol. 62, no. 22, 31 May 1993, NEW YORK US, pages 2778-2780, XP000380906 * the whole document *	7	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H05G G03F
A	---	1,3,6,10	
Y,D	PATENT ABSTRACTS OF JAPAN vol. 14, no. 308 (E-947) '4251! , 3 July 1990 & JP 02 100297 A (MITSUBISHI ELECTRIC CORP), 12 April 1990, * abstract *	2	
A	--- -/--	1,10	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 April 1998	Horak, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 1013

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	WO 95 25370 A (BOARD OF TRUSTEES OF THE UNIVERSITY OF ILLINOIS) 21 September 1995 * page 1, line 1 - page 5, line 1 * * page 20, line 13 - line 27 * -----	1,3,4,6,10	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 April 1998	Horak, G

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T : theory or principle underlying the invention
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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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